



How the HYPATIA analysis tool is used as a hands-on experience to introduce HEP to high schools

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Abstract

“HYPATIA” is a tool for interactive analysis of data from the ATLAS experiment at the Large Hadron Collider of CERN. It has been created by the authors and has been evolving over a number of years. It is available in a downloadable version, which is regularly used in the International Masterclasses, and an online version which now exists in the form of a webapp. Furthermore, the data from ATLAS, which are necessary for performing different educational analysis paths, are available online. Such examples of interactive analyses vary from the estimation of the magnetic field of the ATLAS solenoid magnet, to detecting “pseudo” Higgs events. These applications have been used in recent years in a large number of schools in the form of a half-day mini local (or even remote) masterclass. These activities have been supported by various European Union outreach programs which give emphasis to promoting science education in schools through new methods based on the inquiry based techniques: questions, search and answers. This way we have been able to introduce cutting edge research in particle physics to High Schools, bridging the gap between research and school hands-on experience.

Keywords: ATLAS, LHC, HYPATIA, ATLAS event analysis tool

1. INTRODUCTION

Particle physics has rarely (if ever) been part of the high-schools curricula in most countries. The same is true to some degree about the ideas of modern physics in general. School curricula in most countries include only the basic physics concepts that have been known for centuries. The demonstrations/experiments available date back to the beginning of the 20th century. Moreover, no information is given about the modern research and the cutting-edge technologies. The European Union (EU) has long recognized the need of bridging the gap between school science education and pioneering research. Through the support of several

EU outreach programs, the HYPATIA event tool [1] has been developed and implemented in several inquiry based education contexts. HYPATIA is an innovative hands-on event visualization tool which aims to introduce the students to the most modern particle physics research. It aims to stimulate students’ interest with science by involving them to interactive analysis of data from the ATLAS experiment [2] at CERN.

The recent discovery of the Higgs boson has attracted large media coverage generating great public interest. The students, through the usage of HYPATIA, can try to “discover” the Higgs boson themselves. In addition, their teachers get extensive help in their effort to explain the most recent experimental results, subjects which they have not been trained to explain. In this

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way both students and teachers get engaged with playful learning of High Energy Physics (HEP).

2. THE EU OUTREACH PROJECTS WHICH HELPED DEVELOP THE HYPATIA TOOL

As mentioned in the introduction HY.P.A.T.I.A (Hybrid Pupils Analysis Tool for Interactions in ATLAS) is an event display for data collected by the ATLAS experiment at CERN. It has been developed at the University of Athens since 2007, in cooperation with the Belgrade Institute of Physics during the first years (2007-2010). The development was initially supported by the ATLAS outreach group, and subsequently by the following EU outreach projects:

1) Learning with ATLAS@CERN (2009-2011) [3]. This project was coordinated by one of the authors (C.K); its main objective was to use the information material and the data from the ATLAS experiment in order to build educational scenarios for schools and universities. It formed a rich repository of HEP resources relevant to the ATLAS experiment [4]. This way it demonstrated and applied the innovative pedagogical approach of inquiry learning to communities of students, teachers and the general public.

2) PATHWAY to inquiry based science education (2011-2013). The project focused on teachers and proposed a standard-based approach to teaching science, in general and not only HEP, by inquiry. It outlined instructional models, motivated the teachers to adopt inquiry based techniques and activities in their classrooms, and offered access to a unique collection of open educational resources and teaching practices [5].

3) Discover the COSMOS: e-Infrastructures for an Engaging Science Classroom (2010-2012) which was coordinated by one of the authors (C.K). The Discover the COSMOS activities introduced students to concepts and ideas of big science in the fields of Astronomy and HEP. During its two year course, it implemented a great number of activities that interconnected schools and research centers following a detailed pedagogical framework. The project developed an innovative learning environment [6] which brings together more than 95,000 science education learning objects and activities connected to the science curriculum from Astronomy, Space Physics and HEP. The consortium managed to mobilize an extremely large number of users (5,700 teachers and approximately 31,000 students) and to involve them in numerous activities, at schools and at research centers.

4) Go-lab [7]: Online science labs, started in November 2012 for a four year duration. Its goal is to open

up the remote science laboratories, their data archives, and virtual models (“online labs”) for large-scale use in education. Go-lab is addressed to students, teachers and lab-owners. During its first year of operation it has already created a pilot federation of several online labs from worldwide renowned research organizations (e.g., CERN, ESA) and from several selected universities. Four HYPATIA scenarios which will be described in sections 4 and 5 are included in the Go-lab portal as Inquiry Learning Spaces (ILSs). The structure of each ILS is such that it includes all steps of the inquiry learning methodology, namely: orientation, conceptualization, investigation, conclusion and discussion.

5) Inspiring Science Education (ISE). The ISE project [8] began in April 2013 and will last till July 2017. It aims at contributing to the implementation of the “Digital Agenda for Europe” in particular contribute to mainstreaming the eLearning for modernization of education and training. The ISE designs, plans and implements large-scale pilots to stimulate and evaluate innovative use of existing eLearning tools and digital resources for scientific disciplines and technology (STEM related subjects), enhancing science learning in 5,000 primary and secondary schools in 15 European Countries. During its first year it has already reached 500 schools in Europe; all Greek schools participating in the pilot phase have received training in the HYPATIA HEP scenarios through mini-masterclasses (see 6.2).

3. DESCRIPTION OF THE HYPATIA TOOL

The full-featured offline version is based on the ATLANTIS event display created by the University College London and Birmingham University teams of ATLAS [9]. HYPATIA (Figure 1) offers a graphical representation of the products of proton collisions registered by the ATLAS detector. Students using the event display can interact with the events and in this way study the fundamental building blocks of nature and their interactions. At the same time, they learn how the gigantic state-of-the-art detector works. This gives students an insight into the research being done at CERN and stimulates an enthusiastic interest in it and in possible scientific careers. The full version of HYPATIA has been used in the International Masterclasses (IMC) [10], [11] (see 6.1) unofficially since 2007 in Athens and officially since 2009 worldwide. It uses java and is therefore compatible with most operating systems (Windows, Linux, OSX, Solaris). This version is updated every year with new functionality to better serve the IMC’s needs as one of the two ATLAS exercises -the Z path [12]- evolves.

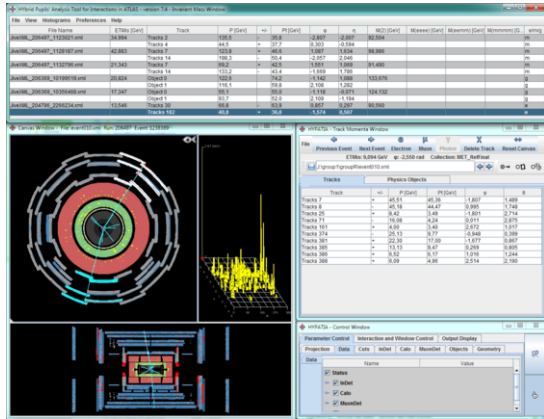


Figure 1: Offline version used in the International Masterclasses

The latest additions include the use of photons in order to study the $H \rightarrow \gamma\gamma$ decays along with the corresponding histograms and export functions for the results. In the most recent HYPATIA-v7.4 2014 Masterclass version, the histograms of the decay products of $H \rightarrow ZZ \rightarrow 4\ell$, ($\ell = e, \mu$) are plotted separately according to the type of lepton combination, namely $4\ell = 2e2\mu, 4\mu, 4e$. The offline version of HYPATIA is freely available at [13] along with event files, instructions and supporting material. This version has also been used in the context of Nuclear Physics laboratory for 4th year undergraduate students at the University of Athens.

In addition to the offline version, since 2010 the University of Athens has developed an online version of HYPATIA [14] which is simpler to handle events and aimed squarely at educational use. The first iteration of the online version was implemented as a java applet and was used from 2010 until 2013. Due to the java requirement which limited the target use (not supported by mobile operating systems) and the increasing difficulty in supporting java in recent browser versions due to security concerns, a new iteration was developed in 2014. This is implemented as a web application and is based on HTML5 and javascript which are supported by all operating systems, both pc based (windows, linux, etc) and mobile (android, ios, windows phone). In addition, the new iteration does not require the installation of any additional software (such as java) and runs everywhere out of the box. The web application is designed to be simpler to use than the offline version of HYPATIA, while still containing all the functionality necessary for the exercises. It is especially easy to explain to students, doesn't need any deployment in classrooms or computer

laboratories and can be used in any device available, even tablets and smartphones. The web application (online) version of HYPATIA shown on Figure 2 is available at [14] and includes event files for all exercises (Z, Higgs, Conservation of momentum and Magnetic field measurement), instructions (including videos), help, exercise descriptions and solutions. Both the application and the supporting website are available in Greek, English, German and French. The great advantage of the

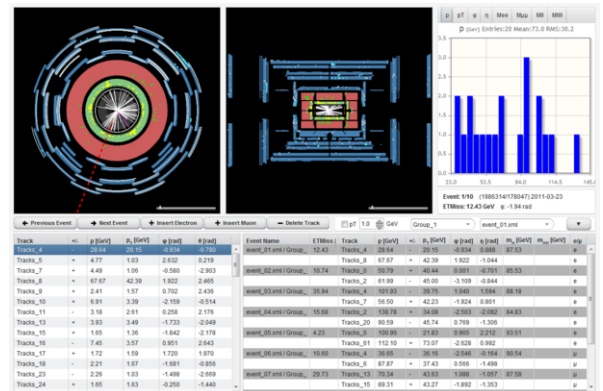


Figure 2: New online version of HYPATIA written in Javascript and HTML5

web application is its flexibility and possibility of creation of personalized exercises/labs by the instructor. It includes four different versions with increasing level of difficulty; level four (HYPATIA4) being the full version which permits the reconstruction and histogramming of the Z and Higgs bosons.

4. HEP SCENARIOS OF HYPATIA

As mentioned above, the Go-lab portal already includes two full ILSs dedicated to the discovery of the Z^0 [15] and Higgs boson [16] respectively. By following the ILSs step-by-step instructions are given to students and teachers, so that the scenarios can be performed in class without external help. A search for the Z^0 and Higgs boson can also be performed using HYPATIA4 online, but in this case the help of a HEP scientist (either visiting or remote) is necessary. The same is true for the offline version of HYPATIA, where the Z path instructions [12] have to be followed with external help.

In the Z boson exercise the students study the $Z^0 \rightarrow e^-e^+$ and $Z^0 \rightarrow \mu^-\mu^+$ decays. They are guided to learn how to separate the characteristic signatures which the muons or the electrons leave in the ATLAS detector

by studying the event display in two mutually perpendicular views. After the identification of two opposite charged muons or electrons, the corresponding tracks are inserted into the invariant mass table and their invariant mass is automatically calculated. By studying the invariant mass histogram, m_{ll} , the user is instructed to determine whether she/he has found a “resonance” corresponding to the mass of the Z^0 boson, and in this way infer its existence. The histograms of the invariant masses of $Z^0 \rightarrow 2e$ and $Z^0 \rightarrow 2\mu$ (m_{ee} and $m_{\mu\mu}$ histograms) are also available, so the user can compare the two masses and their differences, if any. The user should also observe the finite width of the resonance and draw conclusions about the lifetime of the boson and the experimental errors.

The Higgs exercise builds upon the experience gained during the “Discover the Z boson” exercise. This time the students look at Higgs boson decays into four leptons ($H \rightarrow 4l$) which can be two pairs of electron-positron or muon-antimuon or one of each. The user looks for two Z bosons in the event and inserts the decay products of each one into the invariant mass table. This way she/he can determine the mass and width of the Higgs boson² through the corresponding m_{llll} histogram.

5. THE HYPATIA SCENARIOS DIRECTLY CONNECTED TO THE SCHOOL CURRICULA

The Go-lab portal also contains two new scenarios directly connected with the school curricula: these exercises have short duration, are aimed at younger students and can be easily implemented in the classroom in the course of one lesson plan.

The first exercise, aims to demonstrate that the conservation principles [17] apply to big science as well, namely from the macroscopic to the microscopic world. The cross-section of the ATLAS detector perpendicular to the proton beams (z-axis) is used to demonstrate the principle, since both before and after the collision, the total momentum is zero. In this exercise we use specially selected and filtered events with very few charged tracks (muons, which are easily identifiable). The students should add up all momenta of the tracks either by vector addition or by adding the x,y components. The

kinematic quantities of each track (direction, momentum) are given in the table shown in the lower left hand side of Figure 2. Then by calculating the vector opposite to the sum of the momenta of all particles, the students either confirm that it is almost zero (experimental errors always exist in real data) or that a substantial amount of momentum is missing in a particular direction. This may be an indication of an invisible neutrino. They can also compare the result of their calculation with the corresponding quantity calculated by the web app E_{Tmiss} and the direction of the resulting vector (in the x-y plane) to the red dotted line shown on the canvas which is the corresponding quantity calculated by the webapp.

The philosophy behind the second exercise [18] is to apply the Lorentz law of the force exerted on a particle by the magnetic field in order to calculate the strength of the magnetic field of the ATLAS solenoid surrounding the Inner Detector. ATLAS measures the momentum of charged particles by bending them in the magnetic field of its several magnets. The inner magnet is a superconducting solenoid creating an almost uniform field of 2 Tesla. The magnetic field lines are parallel to the beams, thus the tracks of the charged particles are bent by the Lorentz force in the x-y plane (transverse plane, plane of Figure 2). The force exerted in this plane is the centripetal force which is equal to the Lorentz force:

$$(m * v_T^2)/R = q * v_T * B \quad (1)$$

where v_T is the velocity of the charged particle calculate in the plane transverse to the colliding beams

Taking as known the strength of the magnetic field in Tesla, the absolute value of the charge q and estimating the radius of curvature of the tracks R in meters, ATLAS calculates the p_T (the transverse component of the momentum) of the charged tracks:

$$p_T(\text{GeV}/c) = 0.3 * R(m) * B(T) \quad (2)$$

In the exercise the user treats the p_T as known (by selecting a track and looking at its value in the table shown in the lower left hand side of Figure 2. The R (arc radius) is calculated by HYPATIA by right clicking on three well separated points on the curved track and fitting a circle to it³. The result obtained by the user is the strength of the field in Tesla, since HYPATIA software solves equation (2) for B. After performing this calculation for a small number of tracks, the user obtains the mean value of B and the instructor can pursue a discussion of statistics, outliers etc.

²The events contained in the “Higgs” online file are not real data from ATLAS but are “pseudo” events produced by overlapping two real Z events, therefore the mass of the few “Higgs” events comes out close to $2m_Z$.

³In order to have tracks which are bent within the 2.4 m diameter of the solenoid only charged tracks with transverse momenta between 500-700 MeV/c appear in the list of tracks of this exercise.

6. ACTIVITIES FOR IMPLEMENTATION OF HYPATIA IN THE SCHOOL CLASS

Since 2007 when the first of the five European projects was launched and the first offline version of HYPATIA was written, outreach teams from the consortium, the participating countries and beyond have been using HYPATIA in the context of masterclasses, e-Masterclasses and mini-masterclasses. Summer schools, teachers's training sessions and contests have also been organized in the framework of the above mentioned EC projects to effectively support and disseminate the widespread use of the proposed activities in the participating countries and beyond (i.e. Australia, Canada, Bulgaria, U.S.A. etc).

6.1. International Masterclasses

The IMC organized each March by the International Particle Physics Outreach Group (IPPOG) [19] provide an opportunity for high school students and their teachers to be “scientists for a day”. Their goal is to familiarize the teachers and students with the cutting-edge research performed at CERN and in the LHC in particular. Each year about 10,000 high school students from 41 countries all over the world go to one of about 150 nearby universities or research centres for one day in order to unravel the mysteries of particle physics by analyzing real data.

During the day-long activity the local organizers (HEP scientists from universities or research centres) explain the ideas of particle physics and its importance in basic research while demonstrating the fundamentals of particle detector operation and explaining the way particles interact and leave characteristic signatures in the detectors according to their type.

HYPATIA is used in the ATLAS Z path activity [12] of the IMC's. This is the most popular exercise used by 67 institutes worldwide in 2014. The students use the HYPATIA offline tool and real events from the ATLAS detector in order to identify and study decays of short-lived particles such as $Z^0 \rightarrow 2l$, $J/\psi \rightarrow 2l$, $Y \rightarrow 2l$, $H \rightarrow 4l$ and $H \rightarrow 2\gamma$ decays. After the end of the event analysis, the students compare their results with those of students from about 5-6 other institutes which performed the same analysis, during a videoconference.

6.2. Mini Masterclasses and e-Masterclasses

The mini-masterclasses and e-masterclasses were pioneered by the Discover the COSMOS project and are smaller scale half-day masterclasses where the students can stay in their own school (or go to CERN) and are guided either remotely (by video-conferencing) or

by a few visiting scientists with the simultaneous help from their trained teachers. For these masterclasses the students use the web application version of HYPATIA which allows easy use in any internet enabled device without the need for deployment. Usually these masterclasses are accompanied by a virtual visit to the ATLAS control room. This way the students have the opportunity to see the scientists at work doing their shifts and discuss with them in a long question and answer session, following the presentation of the mini-experiment. Figure 3 shows a map of the very recent masterclasses performed in Greece during the last two years, which covered almost all regions of the country by visiting about 50 schools. Similar events were also performed

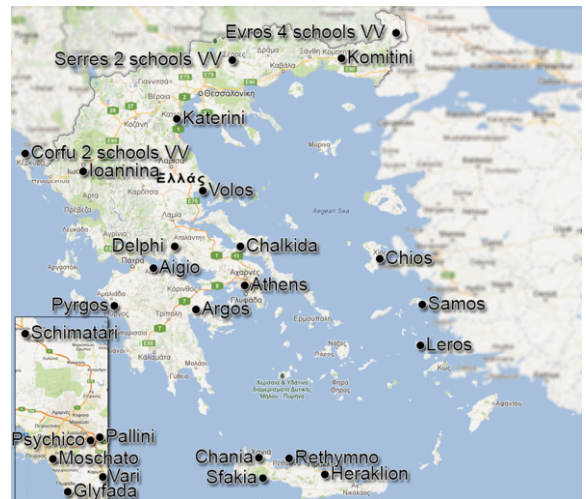


Figure 3: Mini masterclasses in Greece

in other European countries as well as at CERN, where students from four different countries came together for such events. Moreover, during the 2013 CERN Open Days, a large crowd of about 3,000 visitors came to the ATLAS stand and had hands on experience with the on-line HYPATIA tool as well as with MINERVA (Masterclass INvolving Event Recognition Visualised with Atlantis), Collider, LHC game and CERNland.

6.3. HYPATIA Teachers training during CERN exhibitions

In addition to summer schools a large number of HYPATIA training workshops were organized during the visits of the CERN mini exposition in Greece as well as in Spain and Cyprus. The mini expo, for its 2011-2012 tour, was upgraded with new posters, hands-on activities and combined with educational activities. In every one

of its six stops in different Greek cities (Athens, Heraklion, Patras, Alexandroupolis, Kavala and Volos) several local teacher workshops were organized, training more than 650 teachers.

In the spring of 2014 the “Accelerating Science” CERN exposition came to Athens for a month. It was hosted at the premises of the Eugenideio Foundation (science museum and planetarium). The exhibition was a huge success with more than 11,000 visitors, among them 4,000 students from 92 schools. Also about 120 teachers were trained in the use of HYPATIA in three workshops held in parallel with the exhibition.

7. Conclusions

During the past two years a great effort has been made to exploit the recent publicity about CERN and the Higgs boson, in Greece and in Europe. The International Masterclasses, the mini Masterclasses and the two CERN exhibitions have helped thousands of people, ranging from the general public to students and their teachers to get acquainted with HEP and CERN. The number of European schools visiting CERN has risen significantly. More specifically the number of Greek schools visiting CERN during the past two years has increased by 23% from 2012 to 2013 and a further 31% from 2013 to 2014. CERN can no longer accommodate them! Furthermore, an example of the impact that all those actions have had on Greek students and teachers, is the fact that Odysseus’ Comrades team from Varvakios Pilot School in Athens were joint winners of the Beam line competition of CERN. The teacher who led the team, A. Valadakis, has been trained in the use of HYPATIA and participated with his students at several masterclasses. He has also brought his students at CERN several times. This is a great example of the impact of such actions extending beyond the classroom and the given exercises. It shows that under the right circumstances, students and teachers can build upon the knowledge they gain through those actions and eventually construct their own exercises or experiments.

8. Acknowledgments

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